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Tao Liu
Lanzhou University of Technology

Bin Peng
Lanzhou University of Technology

GEOMETRY MODELS OF EMBEDDED-TYPE-SHAFT SCROLL AND THEIR INFLUENCE ON DYNAMIC PROPERTY OF SCROLL MACHINE

Tao LIU*, Bin PENG
Scholl of Mecheno-Electronic Engineering, Lanzhou University of Technology
Lanzhou, Gansu Province, China
Phone: (0931)2973860
Fax: (0931)2757293
E-mail: liutao1971@lut.cn

ABSTRACT

A renewed interest in the reduction of scroll compressor overturning moment has generated a lot of attention in recent years. An important way to better performance of a scroll compressor is to reduce friction and leakage. Because the relative position of scrolls is altered thus the ideal working condition is changed, overturning moment could result in more friction and leakage power loss. In order to eliminate the overturning moment associated with conventional scroll compressor, a novel practical wrap design is presented. This unique scroll profile design makes embedded-type shaft possible. Three types of geometry model of scroll compression mechanism without overturning moment are established. By using these models, the overturning moment is reduced or eliminated obviously and with no increase in scroll size. Furthermore, the gas forces are reduced greatly as well.

1. INTRODUCTION

The scroll compressor has the characteristics of simplicity, reliability, high efficiency and low level of noise and vibration. It therefore is becoming popular and widely used in refrigeration and air conditioners. It shows that in scroll type machine, the power loss caused by mechanical friction is about 17%, whereas the power loss caused by is about 8.5%. Therefore, One of the main measure to enhanced the property of scroll machine is to decrease the mechanical friction of the whole set. The overturning moment existed in a traditional scroll compressor is caused by the rotation of orbiting scroll toward fixed scroll. Because overturning moment could alter the position of orbiting scroll and change the ideal working clearance between scrolls, thus more friction and leakage power loss is found in such conventional scroll machines.

A renewed interest in the scroll compressor tipping moment reduction has generated a lot of h attention in recent years. This paper presents a very unique method to eliminate the tipping moments that are caused by to gas forces developed by the scroll set during compression. Our initial design revealed that a through shaft design could reduce the tipping moment, if implemented by simply truncating the inner turns of an involute. This design resulted in mismatched compression chambers and a smaller volume-reduction ratio, where some benefits of the concept are lost.

In our final design, a new geometry is adopted to form the shape of the scroll wrap and its properties are discussed in detail. By this way, as much as 83.7% volume-reduction ratio of conventional scroll compressor is maintained, while the overturning moment is eliminated completely and with no increase in size.

An imperfectly meshed pair of scrolls will generally result in poor efficiency, but well modified pair may lead to better properties. The profile of central wrap will have great effects on geometrical [1] and mechanical characteristics of the whole scroll set. Therefore, the geometry models of embedded-type-shaft scroll appears to be very important and needs to be investigated carefully..

2. GENERAL EQUATION FOR SCROLL PROFILE

2.1 overturning moment generated in scroll set

The gas pressure forces developed within scroll parts are well known to be axial, tangential and radial. Each force varies in magnitude as the crank angle rotates through the 360 degrees of revolution. First of all, tangential gas force generates most of the radial bearing loads. If the midpoint of scroll teeth is O_1, and the midpoint of crank pin is

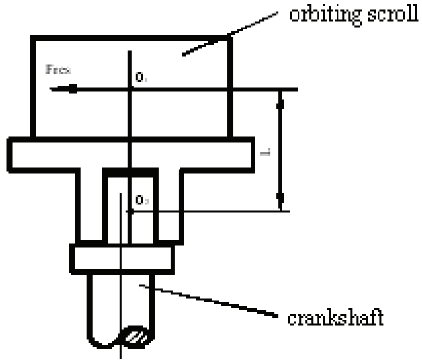

Fig.1 conventional orbiting scroll model

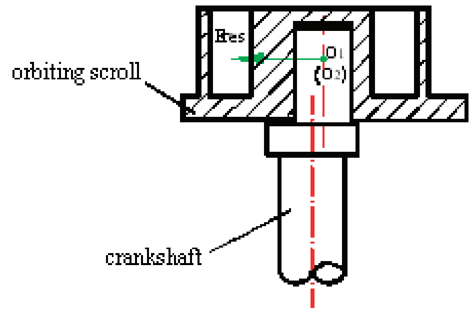

Fig.2 embedded-type-shaft scroll

O_2, As shown in Figure 1, the resultant of axial and tangential gas forces applied at the half height of scroll wrap O_1, thus the overturning moment acted on orbiting scroll is as follows:

$$M = F_{res} L \tag{1}$$

Where L is the distance between point O_1 and point O_2.
For a given displacement, the shorter the wrap length, the higher the volumetric efficiency. Secondly, the challenge is to control the overturning moment M created by the force couple of tangential and radial gas forces. If O_1 coincides with O_2, which means the arm of the force L is made zero, and the tipping moment typical of the conventional design can be totally eliminated, whereas a higher volume efficiency is maintained, Fig 2.

2.2 moving frame based scroll profile

The through shaft [2] may be used to make the arm L zero. In our early design, the central part of involute is trimmed enough to get the shaft through, but the performance of the whole package was unsatisfactory. The volume-reduction ratio was much lower under the given displacement. This means in order to keep a reasonable value of volume-reduction ratio, a longer scroll wrap is required. Machining the long wraps would have a significant negative effect on the design. Furthermore, the internal leakage across the flank tips is excessive incomparable to the calculation due to mismatch of the scrolls.
In our improved design, orthogonal frame is used to describe scroll wrap, a general equation [3] in form of vector function is established for scroll profile. The equation for generating line of orbiting scroll is listed below:

$$\begin{cases} x = \int \rho(\varphi)\cos\varphi d\varphi \\ y = \int \rho(\varphi)\sin\varphi d\varphi \end{cases} \tag{2}$$

The equation for generating line of fixed scroll could be written as

$$\begin{cases} x = \int [\rho(\varphi) + R_{or}]\cos\varphi d\varphi \\ y = \int [\rho(\varphi) + R_{or}]\sin\varphi d\varphi \end{cases} \tag{3}$$

Where

$$\rho(\varphi) = C_0 + C_1\varphi + C_2\varphi^2 + C_3\varphi^3 + \ldots = \sum_{i=0}^{n} C_i\varphi^i \quad (i = 1, 2, \ldots, n) \tag{4}$$

Parameter R_{or} appeared in the above equations is the rotation radius of orbiting scroll. Parameter φ is the tangential angle of any point on scroll profile. Parameters C_i play an important role in the geometric and dynamic properties of scroll compressor and by control of them the shape and feature of scroll set could change.

3. GEOMETRY MODEL OF SCROLL PROFILE

In our design, the main part of scroll geometry is involute of circles, while special modifications are made on the beginning part of scrolls. So the thickness of scroll wraps is uneven, thicker thickness in center part of orbiting scroll left enough space to allow the crankshaft punctuate in. By doing so, the integrity [4] of the geometry is maintained and scrolls match with each other well.

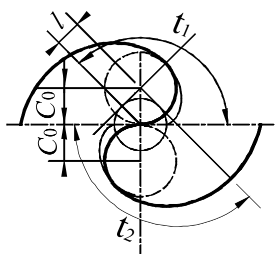

Fig.3 Symmetrical top modification

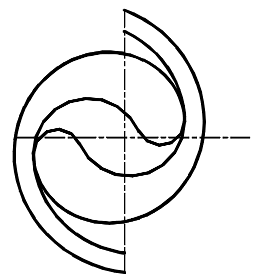

Fig.4 Scroll pairs with symmetrical top wrap

3.1 Symmetrical Top Modification (STM)

In pattern of symmetrical top modification, the top profile of center wrap is circular curve and could be expressed with equation (1) under condition of $i = 0$, $\rho = C_0$. The modification angle [5] t, from where modification arc joints the main involute profile, of both scrolls hold the same value $t_1 = t_2$. And radius of both modification arcs equals to C_0. The generating lines of both scroll pass through origin of coordinate. And the wraps of orbiting scroll and fixed scroll thus formed are symmetrical.

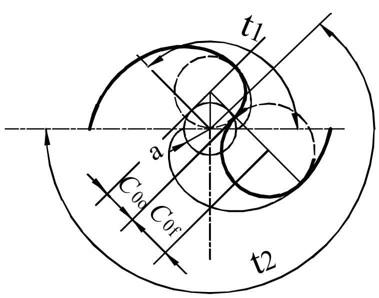

Fig.5 Asymmetrical top modification

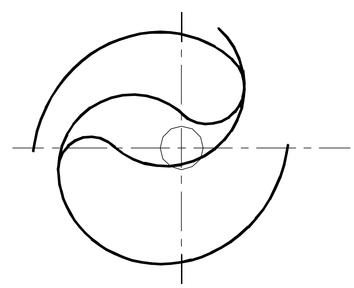

Fig.6 Scroll pairs with asymmetrical top wrap

3.2 Asymmetrical Top Modification (ATM)

In pattern of asymmetrical top modification, the top profile of center wrap is circular curve and still could be expressed with equation (1) under condition of $i = 0$, $\rho = C_0$. But the modification angle t_1 on orbiting scroll is different from t_2 that on fixed scroll. The radius C_{0o} of top generating lines of orbiting scroll is unequal to that of fixed scroll C_{0f}. Only one of circular curves of generating lines passes through origin of coordinate. And the wraps of orbiting scroll and fixed scroll thus formed are asymmetrical, shown in Fig. 5 and Fig.6. Under this condition, the greater the modification angle t_1, the thicker the top wrap of both scrolls. Compare to fixed scroll, orbiting scroll grows even thicker with increase of t_1.

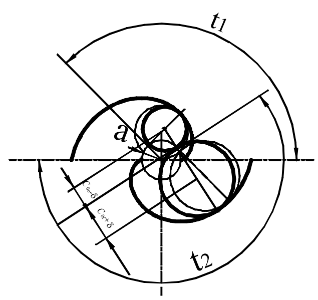

Fig.7 MANPOC modification

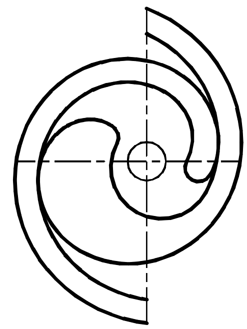

Fig.8 Scroll pairs under MANPOC modification

3.3 Modification Arc Not Pass Origin of Coordinate (MANPOC)

In pattern of Modification Arc Not Pass Origin of Coordinate, the top profile of center wrap is circular curve still under condition of $i=0$, $\rho = C_0$, but the arc radius of top generating lines of orbiting scroll is unequal to that of fixed scroll. Assume the decrease of radius from C_{0o} in ATM pattern for orbiting scroll is δ , the increase of radius from C_{0f} in ATM pattern for fixed scroll would exactly be δ .

Neither of circular curves of generating lines passes through origin of coordinate. And the wraps of orbiting scroll and fixed scroll thus formed are asymmetrical, seen in Fig. 7 and Fig.8. Under the same modification angle t_1, the thickness of top wrap of fixed scroll grows slowly with raise of δ , while the thickness of central wrap of orbiting scroll is more sensitive to the increase of δ .

4. DYNAMIC PROPERTY OF THREE GEOMETRY MODELS FOR PROFILE

4.1 Dynamic property of different geometry models

In the above three models, Dynamic property varies with different design parameters.

In pattern of STM, when crankshaft t is embedded in orbiting scroll, the relatively large tipping moment is eliminated totally. The relatively large axial gas force could be seen in Fig.9 under certain design condition. Because the conjugate engagement of scrolls is satisfied, the curvature variation of meshing point on both scroll profiles is continuous in one period of crankshaft rotation. Thus the axial gas force changes with crankshaft angle continuously.

In pattern of asymmetrical top modification, with the increase of modification angle t_1, the modification curve get involved in engagement earlier, the discharge angle of scroll set becomes smaller and the amplitude of axial force become smaller as well. When crank angle equals to discharge angle, that is $\theta = \theta^*$, the axial force for the asymmetrical model $t_1 = 180^\circ$ and $t_1 = 270^\circ$ is reduced from the condition of $t_1 = 135^\circ$ by 2.86% and 10.22%, respectively.

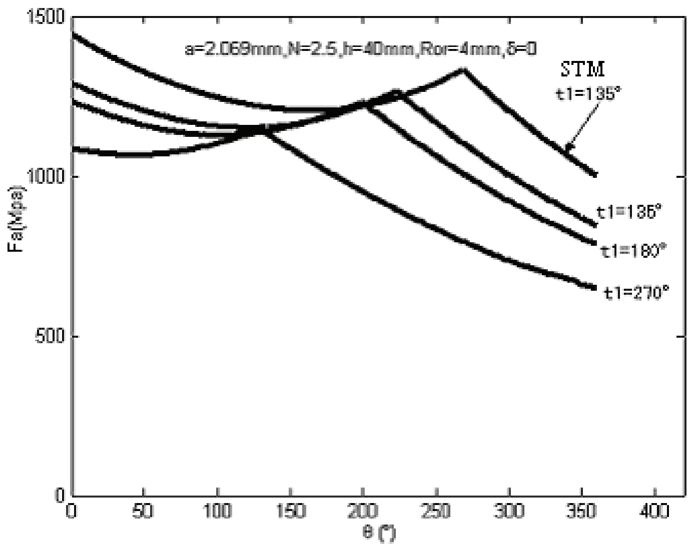

Fig.9 Axial gas force under different modification angle t_1

In pattern of MANPOC, the axial force applied on orbiting scroll with various δ is illustrated in Fig.10. With the increase of δ, the modification curve get involved in engagement later, the discharge angle of scroll set becomes larger and the amplitude of axial gas force increases as well. When crank angle equals to discharge angle, that is $\theta = \theta^*$, and modification angle $t_1 = 135^\circ$, the axial gas force for condition of $\delta = 0$ and $\delta = -1\text{mm}$ is reduced from the condition of $\delta = 1\text{mm}$ by 2.24% and 5.56%, respectively.

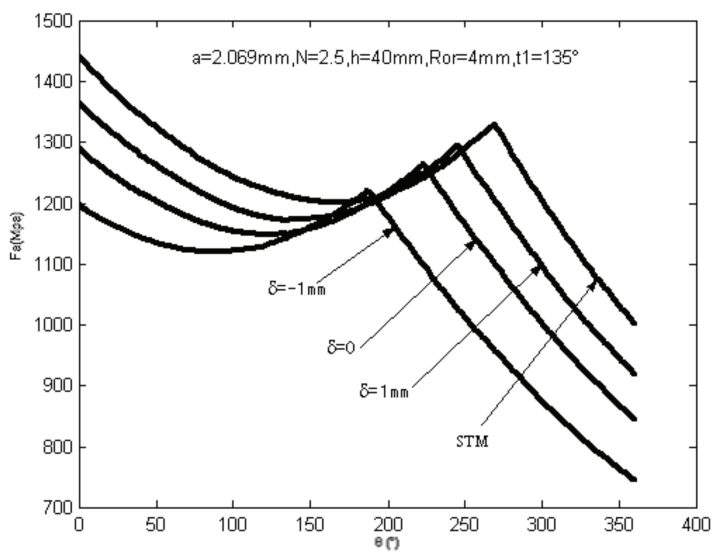

Fig.10 Axial gas force under different δ

4.2 Analysis and discussion

It finds in the three models presented above that the top wrap of orbiting scroll grows thicker with the increment of modification angle t_1. In theory, they could be used as profile for scroll set with embedded shaft. However, the central wrap of fixed scroll is as thick as that of orbiting scroll in pattern of STM, which make the scroll set even much heavier.

Under same modification angle t_1, the volume-reduction ratio of symmetrical model is the largest among the three, as well as the gas force, which could be seen in Table 1.

Table 1: Comparison of calculation value

	$t_1 = t_2 = 135^\circ$ STM	$t_1 = 135^\circ$ $t_2 = 223^\circ$ ATM	$t_1 = 135^\circ, \delta = 1\text{mm}$ MANPOC
Volume-reduction ratio	4.596	3.902	4.230
Axial gas force (MPa)	1350	1290	1320

Because the curvature variation of modification arc is smoother than that of the involute of circle, the earlier the modification arc get in meshing, the shorter the acting line of gas forces, and the smaller of the gas force and its change rate. The choice of modification parameters could be very important to geometrical and dynamic property of scroll machine.
The volume-reduction ratio is in contradiction to thickness of top wrap in scroll set. The improvement of strength of scroll wrap is at the cost of volume-reduction ratio loss.

5. EFFECTS OF MODIFICATION PARAMETERS ON GEOMETRY PROPERTY

Based on the above geometry models, several parameters assembly which could serve as profile parameters of non-overturning moment scroll set is pick out after trying different schemes.
Under design condition of $a = 2.069\text{mm}$, $R_{or} = 5.4\text{mm}$, $N = 2.75$, $h = 40\text{mm}$, $p_s = 0.3\text{MPa}$, $k = 1.4^\circ$, conventional model of scroll compressors with overturning moment, the initial version of our design and the final asymmetrical design with embedded shaft are compared. Following are performance and property comparisons of the three:
(1) The volume-reduction ratio of asymmetrical one is improved about 40.6% from the initial design of 1.98, and account for 83.7% of that of PMP one. Although the ratio for asymmetrical scroll is a little smaller than the symmetrical one, the relatively large tipping moment is eliminated totally.
(2) The power loss caused by internal leakage effect of the final model is 34.5% less than the initial one and is reduced from conventional one by 14.8%. Shorter wrap length and thicker central part of scroll wrap are believed to contribute to the more favored properties.
(3) The mechanical loss resulted from friction and bearings for the final asymmetrical model is reduced from the conventional one with tipping moment by 27.5% and increased from the initial one by 7.2%.
(4) Taking the wrap length, dimension of base-plate, height of the entire package into consideration, the improvements of geometry property found in the latest design are 25% less wrap length and 8.9% reduction of the overall height compared with conventional one, while the radial dimension remains the same. For the initial one, there are 3.4% less of wrap length, 6.8% condenser dimension and 9.1% reduction in height compared with conventional one.

6. CONCLUSIONS

Three geometrical models for scroll set with embedded-type shaft have been presented and the influence of parameters variation on dynamic property of scroll machine is carefully studied in this paper. Based on the above work, the following conclusions can be drawn:

- The wrap thickness at the central portion of scroll can be change through the control of modification parameters. A thicker scroll wrap in general results in a stronger scroll wrap and a smaller volume ratio.
- Theoretically all of the three profile models could be used for scroll set with embedded-type-shaft. By this way, the overturning moment appears in conventional scroll machine could be eliminated or reduced.
- Both numerical simulation and experiment results shows that by utilizing the optimum scroll wrap parameters, the overturning moment could be reduced effectively while most benefits of geometrical property are preserved.

NOMENCLATURE

a	base radius	mm		**Subscripts**
R_{or}	rotating radius	mm	s	suction
N	scroll wrap number	-	o	orbiting scroll
h	scroll wrap height	mm	f	fixed scroll
p	gas pressure	MPa		
k	adiabatic index	-		

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